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Technical note

Warming the premature infant in the delivery room: Quantification of the risk of hyperthermia

Armand Lahana [a], Stéphane Delanaud [b], Romain Erbani [a], Anaïs Glusko-Charlet [a], Estelle Durand [b], Elodie Haraux [b,c], Laurent Ghyselen [b], Jean-Pierre Libert [b], Pierre Tourneux [a,b,*]

[a] Réanimation Néonatale, Pôle Femme – Couple – Enfant, CHU, avenue René Laennec, F-80480, Amiens, France
[b] PériTox, UMI INERIS-01, UFR de Médecine UPJV, Amiens, France
[c] Chirurgie viscérale pédiatrique, Pôle Femme – Couple – Enfant, CHU, Amiens, France

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ABSTRACT

Aim: The efficacy and safety of three polyethylene bags commonly used to prevent hypothermia in premature infants was assessed.

Methods: To simulate transfer from the delivery room to a secondary care unit, a thermally stable, bonneted mannequin (skin temperature: 34.4 °C) was placed in a climate chamber under different conditions: with a radiant warmer, with various polyethylene bags (open on one side, closed by a draw-string at the neck, or a "life support pouch" with several access points) or without a bag.

Results: With the radiant warmer turned on, the mean reduction in heat loss from the nude mannequin was 50.8 ± 1.7% ($p < 0.0001$, vs. warmer off). The mean reduction in heat loss (vs. no bag) was 55.0 ± 0.9% for the drawstring bag, 49.0 ± 2.2% for the standard bag ($p = 0.0001$), and 48.1 ± 0.7% for the life support pouch ($p = 0.006$). When a radiant warmer + polyethylene bag were used, heat stress (body temperature: 38 °C) and severe hyperthermia (40 °C) occurred after 11 and 34 min, respectively.

Conclusion: Caution must be taken when using a radiant warmer and polyethylene bag with a premature infant. Heat stress can occur in only 11 min. Continuous body temperature monitoring is therefore required.

Introduction

Each year, over 15 million neonates are born prematurely – accounting for 10% of births worldwide. Most of neonatal mortality is linked to the prematurity. However, hypothermia in the delivery room is also an individualized factor of neonatal mortality and morbidity [1,2]. Preterm and low-birth-weight newborns are particularly at risk, since (i) their thermoregulatory mechanisms are not efficient, and (ii) their body heat losses to the environment are greater than those of adults [3–5]. In the first few minutes after birth, the core body temperature (T_b) is no longer regulated by the intra-uterine environment, and so the likelihood of body cooling is greater [6,7]. T_b must be maintained within the normothermic range (between 36.5 and 37.5 °C) [8]. Outside this range, a 1 °C decrease in body temperature is associated with a 28% increase in neonatal mortality. Hence, the newborn must be protected against the external thermal fluctuations in the delivery room [8–10]. In 2015, the International Liaison Committee on Resuscitation (ILCOR) published guidelines to prevent hypothermia at birth: drying the newborn with a pre-warmed blanket and then wrapping it in a plastic bag or a cotton wrap; using a radiant warmer and/or a warming mattress in the cot or incubator; increasing the room temperature and using warmed, humidified resuscitation gases [8–10]. Although these procedures clearly decrease the risk of hypothermia, several studies have found that heat stress (defined as $T_b > 37.5$ °C) is frequent in this setting [11–14].

The objectives of the study were to assess different rewarming methods recommended by the ILCOR and to establish the risk of heat stress by calculating the time to hyperthermia (especially with regard to their potential additive effects). For safety and ethical reasons (given that the experiments were carried out near physiological limits), we used a physical model (a thermal

Abbreviations: BLiSP, Baby Life Support Pouch; Tb, body temperature; ILCOR, International Liaison Committee on Resuscitation; DSB, polyethylene bag with a drawstring closure at the infant's neck; PE, polyethylene bag, open at the infant's neck; SD, standard deviation.

* Corresponding author at: Réanimation Néonatale, Pôle Femme – Couple – Enfant, CHU Amiens, avenue René Laennec, F-80480 Amiens, France
E-mail address: tourneux.pierre@chu-amiens.fr (P. Tourneux).

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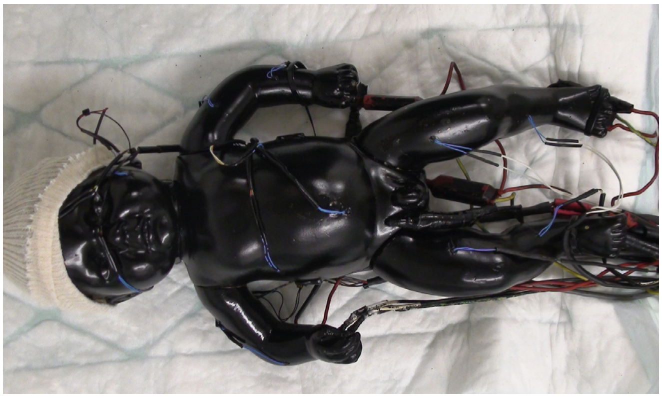

Fig. 1. Thermal mannequin representing an newborn with a body weight of 1800 g.

mannequin previously validated [15]) that simulates heat transfers between the newborn and the environment.

Materials and methods

The model

The thermal mannequin represents an anatomically proportioned newborn with a body weight of 1800 g and a body surface area of 0.150 m^2, previously validated (Fig. 1) [15–19]. The mannequin is cast in copper and was painted matt black, to have the same emittance as the human skin for infrared wavelengths (0.95W m^{-2}).

Each of the mannequin's anatomic regions was warmed by a resistance wire. The mannequin's regional temperatures were measured with sensors (series 409 A, Yellow Springs Instruments; accuracy: ± 0.10 °C, YSI Inc., Yellow Springs, OH, USA) attached to the outside surface. Eight sensors were located on the head (average surface temperature: 35.4 °C), with six on the trunk (34.8 °C), two on each upper limb (32.5 °C), and two on each lower limb (34.3 °C). These temperatures correspond to those recorded for thermally stable (normothermic) newborns in the delivery room [6,17]. The mean surface temperature (T_{sk} = 34.4 °C) was calculated by weighting each local temperature according to the segment's surface area.

The amount of heat emitted by the radiant warmer (expressed as a percentage of the maximum output) was adjusted manually, as it is typically the case in the delivery room [8,9]. For practical and technical reasons, the heat output was set to 30%; the mannequin does not have a cooling system and so ceases to operate if too much heat is gained.

We continuously recorded the surface temperatures, and the electric power supplied to the mannequin.

Materials

The various means of preventing hypothermia in the delivery room were compared with a reference condition: the bonneted but otherwise unclothed mannequin with the overhead radiant warmer turned on (Air-Shields Resuscitaire RW82VHA-1C, Hill-Rom Co. Inc., Batesville, IN, USA). We compared three types of transparent polyethylene bag commonly used in the delivery room: (i) a standard, polyethylene bag lacking a closure system (houses Heltis Line Protection®, Varay Laborix®, Bourges, France; denoted as PE), (ii) a standard, polyethylene bag with a draw-string closure system ("3M™ Steri-Drape™ Isolation Bag 1003", 3 M Company, Saint-Paul, MN, USA; denoted as DSB), and (iii) a new-generation polyethylene "life support pouch" with several re-closable access points (Baby Life Support Pouch, British Polythene Industries PLC, Greenock, UK; denoted as BLiSP). Wrapping a preterm newborn in a plastic bag prevents both evaporative and convective heat losses (since forced convective air movements may occur under a radiant heater).

Protocol

The three bags were assessed in random order. In each experimental condition, we recorded the electrical power required to keep the bonneted mannequin's surface temperatures constant. Trials were performed with the overhead radiant warmer turned on (the ILCOR reference condition) or off. We considered that the difference in wattage input between each trial and the reference condition correspond to excess heat energy stored in the body as a result of the bag and/or the radiant heater. All the experiments were performed in a climate chamber reproducing the thermal conditions encountered in the delivery room, as recommended [8,9,20] (air temperature: 24 °C; relative humidity: 50%; air velocity: < 0.2 m/s, ensuring minimal convective heat exchanges). For each experimental condition, 5 measurements were made and data were recorded for 60 min (after the 30-minute thermal stabilization period).

Calculations

The times to onset of a simulated T_b of 37 °C to 43 °C were calculated from the excess body heat stored in each condition, using the following equation:

$$\Delta T_b = \Delta S (W_t C_p)^{-1}$$

where ΔS is the excess body heat in kJ/h (i.e. the difference between the heating power supplied to the nude and that supplied to the wrapped mannequin), W_t is the newborn's body mass (in kg), Cp is the specific heat of the body tissues (3.494 kJ/kg/ °C), and ΔT_b is the rate of increase in T_b (in °C/h).

The time intervals needed to progress from 37 °C to 38 °C ($t_{38\,°C}$), from 37 to 40 °C ($t_{40\,°C}$) and from 37 to 43 °C ($t_{43\,°C}$) were calculated as follows:

$$t_{38^\circ C} = 3.49 W_t \Delta S^{-1};\ t_{40^\circ C} = \left(3.49 W_{t\,x}{}^{3}\right) \Delta S^{-1};$$

$$t_{43^\circ C} = (3.49 W_{t\,x}\ 6) \Delta S^{-1}$$

We chose these high temperature levels because a T_b of 38 °C corresponds to the onset of heat stress, 41 °C corresponds to fever, and 43 °C is rapidly lethal in newborns (25).

At thermal equilibrium, the heating power supplied to the mannequin balances the dry heat exchanges. The evaporative skin cooling (E_{sk}) was not measured. To take account of this heat loss in our calculation of the body heat storage **ΔS**, E_{sk} was defined as:

$$E_{sk=} h_{e.}.\omega.\ (P_{skH20} - P_{aH2O}) F_{pcl}.A_{Dsegment}$$

where h_e is the evaporative heat transfer coefficient, ω is the skin wittedness (0.06), P_{skH20}-P_{aH2O} is the water partial vapor pressure difference between the skin and the air, F_{pcl} is the thermal insulation coefficient for the bonnet (0.81), and $A_{Dsegment}$ is the skin surface area of each segment of the mannequin.

The values of $h_{e,}$ ω and F_{pcl} have been published elsewhere [18,19]. P_{skH20}-P_{aH2O} was calculated with a standard table of physical data indicating the saturated water vapor partial pressures at the skin temperature for each segment and at the air temperature (25 °C, with a relative humidity of 50%). When the mannequin was nude (i.e. wearing only a bonnet), Esk was calculated to be 2.16 ± 0.09 (heater on) or 2.27 ± 0.06 W (heater off). When the mannequin was wrapped in a plastic bag, E_{sk} (for the exposed head area only) ranged from 0.57 ± 0.02 to 0.62 ± 0.06 W.

To account for the fact that the metabolic heat production (M) rises with T_b (due to the Q_{10} effect), we calculated M (in W) by

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